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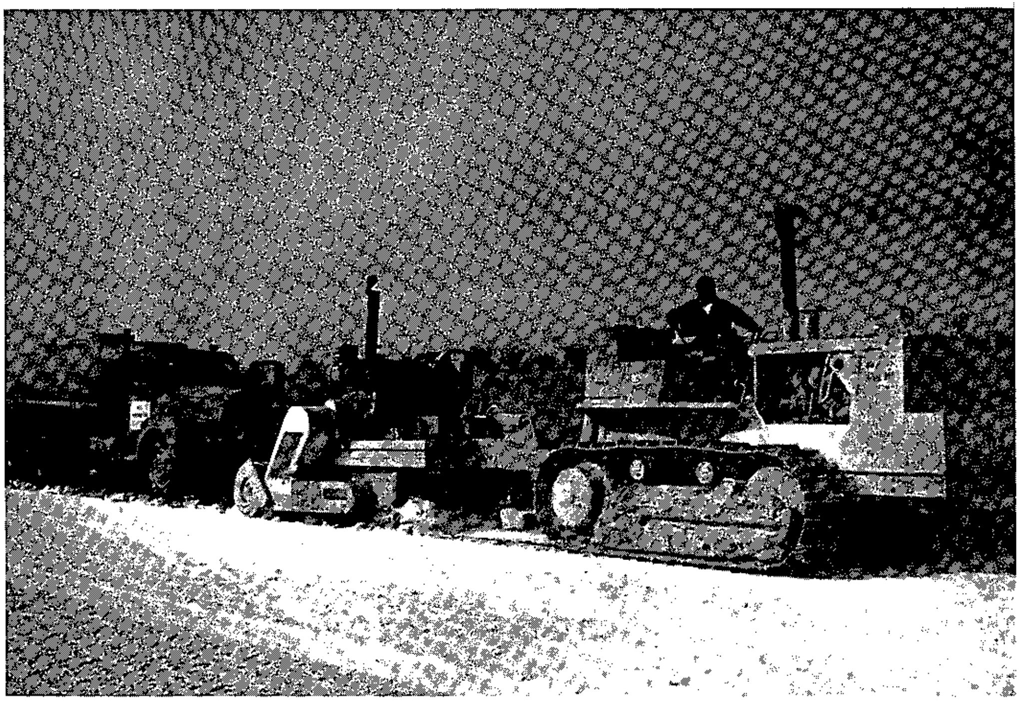

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ACKNOWLEDGEMENTS

This report contains the findings of the research project titled "Determination of Strength Equivalency Factors For The Design of Lime-Stabilized Roadways" which was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

This project was begun under the supervision of George B. Sherman and principal investigator Robert E. Smith. Brian D. Murray was co-investigator and directed the initial phases of the testing. The author also wishes to acknowledge the efforts of Jack W. Knott and Tom E. Neilson who carried out a major portion of the laboratory testing for this study. In addition, appreciation is extended to Betty Stoker and Eileen Howe for their typing and editorial assistance.

TABLE OF CONTENTS

INTRODUCTION

The California Department of Transportation has for many years relied upon the R-value test as the primary means of evaluating the engineering properties of lime treated soils. Although the R-value does indicate improvements in stability through modification of the soil with lime, it does not provide an effective method of evaluating the cementing reaction which occurs. As a result, all lime treated soils used in highway construction have been assigned the same structural design equivalency factor despite the extremely broad range in cementing which does occur with different lime-soil combinations.

Previous studies by the California Transportation Laboratory and several other researchers indicate that an unconfined compressive strength test would be much more effective for evaluating the reactivity of a lime-soil than the R-value test. Since the cementing reaction is relatively slow and may continue over a period of several months, the first issue to be resolved was to establish a laboratory curing procedure which could be used to reliably predict the strengths that could be expected to develop in the roadway.

The second issue requiring investigation and resolution was a means of incorporating the strength of specific lime treated materials in the structural section design formula in lieu of assuming the same strength for all cases. Core samples from existing California roads constructed with lime treated soils have revealed unconfined compressive strengths ranging from 100 to 2000 psi (689 to 13,790 kPa). Variations of this magnitude should be taken into consideration in the design of the roadway structural section.

Along with these two issues was a need to gather more information on the relative cementing reaction which occurs when different lime products are used. In California, the previously required finely ground high calcium hydrated lime is no longer readily available in the quantities necessary for numerous large road construction projects. In its place, high calcium quicklime products in various particle sizes are being marketed. Although use of these products was approved prior to completion of this project, their acceptance was based largely on the work reported herein.

CONCLUSIONS AND RECOMMENDATIONS

1. The unconfined compressive strength of lime treated soils is affected by both the particle size of the lime and the type of lime. Each combination of soil and lime has an effect on the water demand, the compactability, and the ultimate strength of the material. For these reasons it is essential that design tests in the laboratory be conducted using the same lime product, compaction, and soil that will be used during construction.

2. It is a well established fact that the cementing reaction of a lime treated soil may continue over a period of many months. It is concluded from this study, however, that the long term strength gain will generally be relatively small for lime-soil combinations which develop unconfined compressive strengths of less than 300 psi (2068 kPa) after being cured for 7 days at 110°F (43°C). It is also concluded that the chance for a decrease in strength (degradation) due to exposure to free water is much greater for materials which develop 7 day strengths of less than 400 psi (2758 kPa) than for materials which develop 7 day strengths greater than 400 psi (2758 kPa). It is therefore recommended that all lime treated soils to be used in the structural section attain a 7 day unconfined compressive strength of not less than 400 psi (2758 kPa).

3. The unconfined compressive strength of lime treated soil test specimens cured at 110°F (43°C) for seven days provides a fair indication of the strength that can be expected when the same material has been cured for 2 to 3 months at 72°F (22°C). This is assumed to also be indicative of the strength that can be expected within

the first several weeks after placement of the treated material in a roadway structural section. It is recommended that the unconfined compressive strength of laboratory prepared test specimens be used to evaluate the structural value of lime treated soils in lieu of the R-value test. Because of the extremely wide range in strength developed by different lime treated soils, it is also recommended that the California Department of Transportation structural section design procedure be modified to take full advantage of the strengths which do develop. For those materials which meet the minimum strength requirement of 400 psi (2758 kPa) this can be accomplished by using a gravel equivalency factor equal to $\left(.9 + \frac{\text{unconfined compressive strength (psi)}}{1000}\right)$ for the treated soil.

4. The short term sand bath method of exposing test specimens to free water does not effectively identify treated soils which are subject to softening due to continuous exposure to water.

IMPLEMENTATION

The tentative unconfined compressive strength test used in this study is being prepared for adoption as a California Test. Distribution of the test will be made when publication is completed.

A proposed Standard Special Provision is being submitted to the Specifications Committee with the recommendation that lime treated soils have a minimum strength of 400 psi (2758 kPa) when included in the highway structural section.

A change in the California Structural Section Design Procedure which will provide for a variable gravel equivalent factor for lime treated material, depending upon the design strength, is being recommended to the Office of Planning and Design.

Permitting the use of alternate types of lime was implemented in the January 1978 Standard Specifications of the State of California Department of Transportation.

BACKGROUND INFORMATION

Acceptance of the use of lime treated materials in highway construction has increased steadily in California since the construction of two experimental roadway sections in 1948(1). Approximately 800 lane miles of highway have been constructed in California since 1968 using lime treated materials as either a base or subbase. This estimate does not include additional hundreds of miles of lime treated roadways constructed by cities and counties throughout the State.

During the early years of California's experience with lime treatment, there was very little control over the quality of the lime or the structural quality of the completed lime-soil mixture. Prior to 1959, lime was designated simply as "hydrated lime" or, in many instances, "agricultural lime". Quality control of the lime amounted to accepting the product delivered to the project. There were also no specifications for the quality of the lime treated material. Most of these early jobs were considered as research projects and the effects of the treatment with lime were evaluated on the basis of decreased plasticity and increased stability.

As experience increased, specifications were adopted and the quality of the lime came under some controls. Through the years, the requirements for the lime evolved from allowing only a finely ground, high calcium hydrated lime to the present California standard specifications which also permit the use of coarse ground, high calcium quicklime and dolomitic quicklime.

During this same period of time, the R-value test(2) was used to evaluate the effectiveness of lime treatment and to determine the appropriate amount of lime to be added to a soil or aggregate. It has been recognized by the Caltrans Laboratory for some time, however, that the R-value test has inherent limitations which greatly reduce its effectiveness in evaluating the quality of lime treated materials. To explain these limitations of the R-value test, it is necessary to first discuss briefly the reactions that take place when lime is added to a soil.

At least two separate primary reactions occur when lime is mixed with certain clays. First, there is an ion exchange between the lime and soil which causes a flocculation and agglomeration of the clay particles. This first reaction begins almost immediately after mixing the lime with soil and water and is primarily responsible for the beneficial changes in plasticity, shrinkage, and workability characteristics(3). The second primary reaction to occur, if it occurs, is a pozzolanic reaction which cements the soil particles together, forming a relatively impermeable lime-soil layer(4). This reaction is primarily responsible for the marked strength increases noted for many lime-soil mixtures, but it is much slower developing than the ion exchange. In some cases, significant cementing may continue to occur over a period of many months depending on the type and amount of pozzolan in the soil.

Because the R-value test is a relatively short-term test, requiring only 2 days of elapsed time after combining the lime and soil to complete the test, it is possible that only the effects of the ion exchange are reflected in the test results. If, on the other hand, cementing does begin to occur before the R-value test is completed, the test does not have sufficient range to effectively evaluate the extent of this cementing.

The effective range of the R-value test determination is from about 5 for a very plastic clay to 85 for a crushed aggregate base rock. Values greater than 90 are not normally achievable or meaningful. When lime is added to a low quality soil, the flocculation and agglomeration alone may be sufficient to change the soil's stability characteristics enough to achieve an R-value of 85 or more. Thus it is doubtful that the R-value test accurately reflects the structural value of lime treated material that has been in place in the roadway for an extended period of time.

A review of the performance of lime treated roadways in California(5) revealed materials that had achieved unconfined compressive strengths as high as 2000 psi (13,790 kPa). Other materials had not cemented at all, and in some cases the treated material had no more stability than it had before treatment, yet pre-construction R-value tests indicated that each of the materials could be improved to base quality (minimum R-value of 78) by treatment with lime. In cases where high compressive strengths are achieved, the design procedure does not take full advantage of these structural qualities. In some other cases, it appears that the R-value design procedure gives too high a value to materials that may actually lose some of their stability after a period of time.

For these reasons, the R-value test was no longer considered by the Transportation Laboratory to be appropriate for evaluating the structural quality of lime treated materials. It was, therefore, considered necessary to develop or implement a test method which could more appropriately reflect the higher ultimate strengths and determine the amount of lime necessary to insure their occurrence.

One test which had been used by the Transportation Laboratory was an unconfined compression test. Studies by the State of Illinois(6) indicated that lime and cement stabilized plastic soils are similar in flexural strength, modulus of elasticity, failure strains and Poisson's ratio. It was, therefore, assumed that applicable Gravel Factors could be estimated for lime treated soils (in addition to cement-treated materials) on the basis of compressive strength.

The primary objectives of this study were:

1. To develop an improved procedure for assigning an appropriate Gravel Factor for use in the design of roadways which incorporate lime treated materials,

2. To verify the relationship between an accelerated testing procedure (selected for design use) and the long-term "field" strength of lime treated materials, and

3. To determine the relative cementing reaction of high calcium quicklime and high calcium hydrated lime products having various particle size distributions.

MATERIALS AND TESTING

Materials

Twelve soils were obtained from locations throughout the State. Some represented excavation or fill materials from highway projects then under construction while others were taken from cut sections within the right of way of existing roadways. Each, however, represented material that has or could have been used in the construction of a State Highway or County Road. Figure 1 shows the approximate location of each soil sample.

The physical properties of each material are summarized in Table 1. Chemical and mineral content analyses were also made on each soil and the results are recorded in Tables 2 and 3.

It can be seen in these three tables that a wide variety of soils are represented. All of the tested soils with the exception of sample No. 4 are, by definition(7), "silt-clay materials" in the A-4, A-6, A-7-5, and A-7-6 soils groups. Sample No. 4 was classified as A-2-4, "granular material", but bordered on the A-4 classification. The AASHTO classification designations are also shown in Table 1.

Samples of both quicklime and hydrated lime were obtained from three suppliers in California. To minimize any influence on the lime-soil reaction due to lime source, composite samples were prepared by blending together equal portions from each supplier. Blending the limes in this way presented no particular problems since each of the limes met the calcium hydroxide content requirements of the California specifications. However, hydrated lime

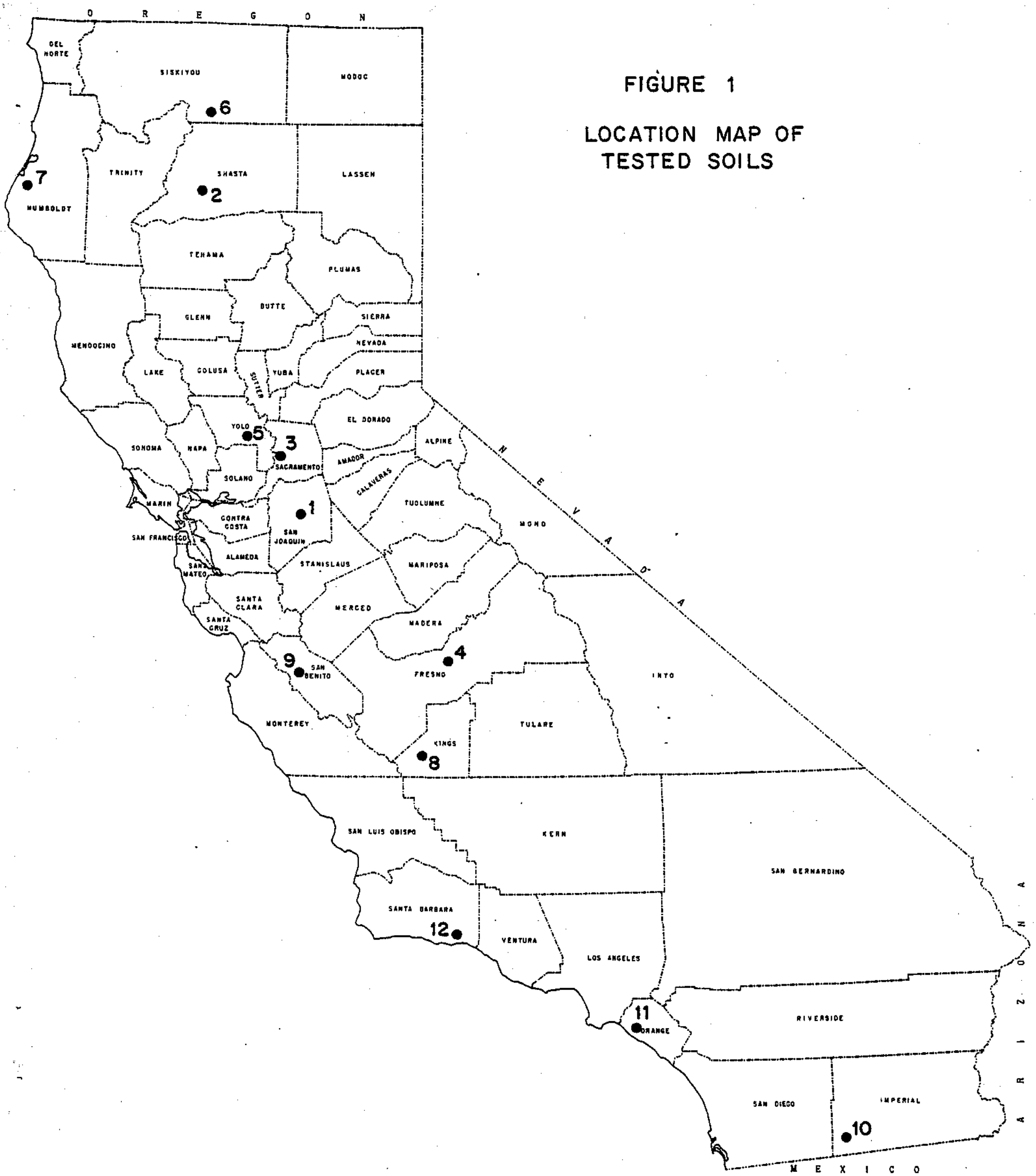

FIGURE 1

LOCATION MAP OF TESTED SOILS

TABLE 1

Physical Properties of Tested Soils

Soil Sample No.		1	2	3	4	5	6	7	8	9	10	11	12
Sieve Analysis													
% Pass No.	4	100	100	100	100	100	100	100	100	100	100	100	100
	8	100	99	99	99	100	97	100	100	99	99	99	100
	16	99	97	99	97	99	93	100	99	98	99	96	99
	30	98	97	97	91	99	91	99	96	94	99	89	99
	50	96	95	96	74	99	86	98	89	82	98	77	99
	100	89	91	93	50	98	80	88	77	65	96	63	97
	200	79	85	90	35	96	73	71	65	49	91	51	94
	5μ	33	39	63	12	51	41	26	32	24	44	23	49
	1μ	21	16	47	5	34	24	14	17	12	25	13	25
Sand Equivalent		5	15	5	20	3	13	4	6	9	4	11	4
Liquid Limit		34	36	56	16	52	51	24	33	31	41	25	50
Plastic Limit		20	25	26	16	22	36	17	19	24	19	15	28
Plasticity Index		14	11	30	NP	30	15	7	14	7	22	10	22
R-value (@ 300 psi exud.)		20	14	8	74	7	62	22	16	40	8	23	22
R-value (by expansion)		--	--	--	--	--	--	--	--	<5	18	--	--
AASHTO/Soil Group and Group Index		A-6 (10)	A-6 (10)	A-7-5 (31)	A-2-4 (1)	A-7-6 (33)	A-7-5 (13)	A-4 (5)	A-6 (7)	A-4 (1)	A-7-5 (22)	A-4 (2)	A-7-5 (24)

TABLE 2

Chemical Analysis of Tested Soils
(Before Addition of Lime)

Soil Sample No.	1	2	3	4	5	6	7	8	9	10	11	12
pH*1 by meter	7.8	7.0	7.8	7.8	8.5	6.2	6.3	7.7	8.0	8.2	8.2	8.2
Soluble Salts ppm*2	940	240	1080	314	980	36	56	9540	560	8950	30	670
" ohm/cm^3*2	2040	8850	1775	6100	2140	58200	37000	355	10900	228	2380	6550
Alkali PPH*2	229	73	301	84	1070	54	30	1271	29	4709	411	89
CaO ppm*2	429	168	408	189	840	336	160	1554	42	47	55	105
CaO ppm*3	<800	2240	6400	<800	5600	980	2100	2100	78	76	59	146
SO_4 ppm*2	nil	nil	82	62	152	nil	nil	5304	nil	1782	nil	nil
SO_4 ppm (total lecco)	<0.1%	193	<0.1%	<0.1%	563	450	226	9475	1550	2875	1675	2400

*1 50/50 proportions of soil and water

*2 Water soluble

*3 Acid soluble

TABLE 3

Mineral Content of Tested Soils

Soil Sample No.	1	2	3	4	5	6	7	8	9	10	11	12
Montmorillonite and Mixed Layer Clay	30-35	10	45		20		20	15	5-10	10-15	10	20-25
Quartz	20	20-25	20	40	20-25	15	25-30	15-20	25-30	25	20-25	20
Feldspar	10-15	25-35	10-15		20	10	20-25					
Muscovite	5-10											
Chlorite	5	5	<5		10	10	5-10			5		
Iron Oxide	<5	10	5		5	5	<5	5	<5	<5	<5	<5
Organic	<5		T	5		<5		T	T		T	T
Slag	<5											
Amphibole	<5	5	5	15	<5	10		5	5		5	
Serpentine	<5				<5			5	T			
Kaolinite		10									5	
Calcite			<5			<5	T	5	<5	20	5	35
Plagioclase/Microcline				35						10-15	35-40	10-15
Degraded Biotite				5					<5	5-10	5	
Pyrite					<5							
Mica					5			5				
Gibbsite						5-10						
Vermiculite						5-10						
Halloysite						20						
Tridymite						5						
Illite							5-10					
Gypsum							<5	5-10				
Plagioclase Potash Feldspar								30-40	40			
Iron Sulfide									<5			
Amorphous									5			
Dolomite										15		5
Zeolite												5

from each of the suppliers met the current requirements for fineness, thus providing insufficient coarse material to prepare a "granular" hydrated lime sample. The quicklime products from the three suppliers differed considerably in gradation. By scalping and adjusting the gradings of the individual products, it was possible to combine equal portions from each source to provide the coarse grade and fine grade quicklime samples desired.

After the study was underway, one of the lime suppliers introduced a very coarse granular quicklime product for soil stabilization work. It was decided to include this coarse product as a fourth lime in the study.

The gradings of the four limes are listed in Table 4. The grading reported for the hydrated lime was determined by ASTM Designation: C110 except that the wash time was set at 15 minutes. The grading of the quicklimes was determined by dry sieving in a mechanical sieve shaker for 10 minutes ± 30 seconds.

TABLE 4
Sieve Analyses of Lime Products

Sieve Size	Percent Passing			
	Fine Hydrate	Fine Quick	Coarse Quick	-3/8 Quick
3/8"			100	100
No. 4		100	99	73
8		99	86	56
16		92	60	41
30	99.8	70	38	34
50		41	13	22
100		26	4	7
200	98.5	16	3	2

Test Procedures

Each of the soil samples was dried at a temperature not exceeding 140°F (60°C) and processed to pass a No. 4 sieve(8). Representative portions of each soil were then treated with 3, 5, and 7 percent of each of the four limes and compacted at optimum moisture into four inch (102 mm) diameter by four inch (102 mm) high test specimens. Optimum moisture was determined for each combination of soil and lime by establishing moisture-density curves using the same compaction procedure used to compact the test specimens.

The method of compaction is described in the tentative California Test Method for "Unconfined Compressive Strength of Lime Treated Soils and Aggregates" attached as Appendix I. Compaction by this test method is accomplished with a kneading compactor operating at a foot pressure of 350 psi (2413 kPa) followed by an increasing "static" load to a total pressure of 350 psi (2413 kPa) applied by a testing press. The material is initially loaded into the compaction mold in twenty equal increments with one 250 psi (1724 kPa) load being applied by the compactor between each increment.

The steel compaction mold used in this method is designed to hold a tin sleeve or liner in which the lime-soil test specimen is compacted. Following compaction, the sleeve containing the test specimen is removed from the mold. The ends are covered with fitted, slip-on caps and wrapped with tape to prevent moisture loss during the curing period.

This compaction procedure is preceded by "loose curing" the lime-soil mixture in airtight containers for 16 to 24 hours after water has been added. This allows the initial flocculation and agglomeration of the soil to occur before the material is compacted. In the field this loose curing period is normally necessary to break up clay clods and make the material workable.

Three techniques were used, individually or in combination, to cure the compacted test specimens. Some were cured at room temerature, normally 72°F (22°C), while in the capped sleeves. It was assumed that this curing would be somewhat representative of the curing that would occur after the material had been compacted on the roadway and covered with subsequent layers of the structural section. Curing times of 28, 180, and 360 days were used to evaluate the rate at which the treated materials gained strength. The actual rate of strength gain for materials placed in construction will of coarse vary as the temperature of the material fluctuates with daily and seasonal cycles. Curing was also done at 110°F (43°C) to accelerate the soil-lime reactions. Studies by others(9,10) have indicated that curing for seven days at this temperature would be approximately equal to three months in the roadway. The third curing technique used was a saturated sand bath. This was accomplished by removing the compacted test specimen from the tin sleeve and surrounding the sample with water-saturated sand. It was felt that this exposure to water would be similar to the exposure the material might be subjected to by groundwater migration or rain water penetrating through the overlying structural layer or through pervious shoulder materials. This curing technique was applied for different lengths of time up to 180 days but was always preceeded by a period of accelerated curing at 110°F (43°C). A summary of the combinations of soil-lime mixtures and curing times applied to each material is presented in Table 5.

TABLE 5

Summary of Lime-Soil Combinations and Curing Times

Lime Content	3%			5%			7%		
Curing @	110°F (43°C)	72°F (22°C)	Sand Bath	110°F (43°C)	72°F (22°C)	Sand Bath	110°F (43°C)	72°F (22°C)	Sand Bath
Curing Time (days)		28						28	
		180						180	
		360			360			360	
	7			7			7		
	5		+2				5		+2
	7		+28				7		+28
	7		+180				7		+180

The structural value of the various lime-soil mixtures and the effects of the different curing techniques were then evaluated on the basis of the unconfined compressive strength of the test specimens. A summary of the unconfined compressive strengths of each soil when treated with the different limes and cured by the several different procedures is presented in Tables 6 through 17. These data are also presented graphically in Figures 2 through 13.

DISCUSSION OF TEST DATA

The load bearing capacities of each soil were measured by the Resistance "R" Value Test(2) prior to treatment and then after treatment with different quantities of lime. The R-value of the untreated soils varied from less than 5 to in excess of 80. Despite the broad differences in physical properties, chemical contents, and mineral contents, each of the soils responded favorably to lime treatment according to the R-value test results. The data listed in Table 18 shows that ten of the soils achieved exudation R-values of 80 or higher when treated with only 3 percent hydrated lime. One soil, No. 5, required 5 percent lime to achieve an R-value greater than 80 while Soil No. 10 was the only material included in this study which never achieved an R-value of 80 even when treated with 7 percent lime. Based on R-value by exudation, each of the soils except No. 10 met the R-value requirements for aggregate base.

TABLE 18

Effects of Lime Treatment on R-Value

	Soil No. 1	2	3	4	5	6	7	8	9	10	11	12
Untreated Soil												
R-value by exudation	20	14	8	74	7	62	22	16	40	8	23	22
R-value by expansion	48	38	24	80+	80+	66	40+	80+	<5	18	80+	30±
Lime Treated Soil												
R-value by exudation with												
3% lime	87	82	86	84	76	80	85	86	82	38	80	88
5% lime	86	87	82	84	86	88	83	88	83	74	80	87
7% lime	85	88	84	84	--	--	--	--	--	71	--	--
R-value by expansion with												
3% lime	80+	80+	80+	80+	80+	76	80+	74	80+	55	80+	80+
5% lime	80+	80+	80+	80+	80+	80+	80+	75	80+	56	80+	80+
7% lime	80+	80+	80+	80+	--	--	--	--	--	55	--	--

When R-value was determined by expansion pressure, Soil No. 10 again failed to achieve an R-value of 80. As can be observed in Table 18, the R-value by expansion was raised from 18 to 55 with 3 percent lime, but additional lime had no further effect on the test results. This sample appears to be different from the others in that it had a dolomite content of 15% and a high alkali content. Soils 6 and 8 also failed to achieve an expansion R-value of 80 when treated with 3 percent lime. Both materials had values close to 80, however, and an additional 2 percent lime was sufficient to raise the value of soil No. 6 to more than 80.

It is therefore concluded that the majority of soils will achieve an R-value of 80 or more when tested with a sufficient amount of lime. Based on current California design procedures (R-value), each of these materials with the exception of soil No. 10 would be considered equal regarding its contribution to the strength and performance of a highway structural section after having been treated with sufficient lime to produce an R-value of at least 80.

On the other hand, <u>the unconfined compressive strength</u> data recorded in Tables 6 through 17 and Figures 2 through 13 emphasize the broad differences in cementing action which occurred with these lime treated materials. When treated with 7 percent hydrated lime, for example, the unconfined compressive strengths varied from approximately 150 psi (1034 kPa) to over 1000 psi (6895 kPa). The use of different quantities and different types of lime brought about even broader ranges in strength. Nine of the soils developed compressive strengths of over 1000 psi (6895 kPa) under certain conditions. Soil 4, however, failed to develop a strength greater than 264 psi (1724 kPa) regardless of the amount of lime, type of lime, or the method or time of curing. Soils 1, 6 and 7 eventually achieve strengths of approximately 500 psi (3447 kPa) when treated with 7 percent lime and/or cured for long periods of time. Quite obviously, these materials would not all contribute equally to the strength, flexibility, and performance of a structural section. In addition, it was concluded in an earlier study(5) that the alteration of soil characteristics, which causes the improvement in R-value, may not be permanent if the secondary cementing reaction does not occur. Thus, the R-value test by itself may lead to inadequate structural section design if, in fact, the lime treated material fails to retain the improved stability that was initially achieved. All available information indicates, however, that the lime-soil reaction is not reversible if a good cementing reaction occurs initially. This does not preclude the possibility that the cemented material may be broken up under traffic due to insufficient strength for the applied loading. Because of the questionable value of the R-value test to properly evaluate lime treated soils on the one hand, and the ability on the other hand of the unconfined compressive strength test to differentiate between ultimate slab strengths of cemented materials, it is believed that the unconfined compressive strength is a more appropriate method of evaluating lime treated soils.

Very little correlation could be found between the unconfined compressive strengths of the treated soils and any of the physical, chemical or mineral properties of the soils listed in Tables 1, 2, and 3. Soil No. 4, which had the lowest unconfined strength of any of the materials tested, was a silty sand and was the only material that was non-plastic prior to treatment with lime. It was also void of measurable clays and contained some organic material which might explain the apparent lack of chemical alteration. The obvious reason for the low strengths with this material was the lack of pozzolans necessary for the cementing action which are normally found in clays. It should be possible to "sort out" soils that would not be likely to respond to lime treatment on this basis. Soil

No. 6, which had the second lowest strength when treated with hydrated lime, contained about 45 percent clay but none of the montmorillonite or mixed layer type.

The recorded data also make it very evident that the resulting unconfined compressive strength is affected not only by the characteristics of the soil, but also by the characteristics and amount of lime and by the curing procedures. The effects of these variables will be discussed individually in the following pages.

Effect of Lime Type on Reaction with Soil

There is no apparent consistent relationship between the type and grading of lime and the strengths that were developed when treating different soils. In many cases, the quicklime products brought about higher strengths than the hydrated lime. This should be expected since quicklime has approximately one-third more available calcium oxide than an equal amount, by weight, of hydrated lime. In other cases, however, the strengths developed by adding equal amounts of hydrated lime were comparable to the strengths achieved with quicklime. In many instances, this probably occurred because the maximum amount of lime which could react with the soil had been exceeded and any additional calcium oxide, whether in the form of a more concentrated lime or simply a higher percentage of lime, had little or no significant effect on the reaction. The average strengths of all the test soils are plotted in Figure 14. It is obvious in this graph that the quicklime provides more benefit than hydrated lime at 3% but at 7% there is no significant difference in strength regardless of the type of lime.

A few materials developed greater strength when treated with hydrated lime than when treated with some of the quicklimes. Soil No. 9, for example, developed a strength of nearly 2,000 psi (13,790 kPa) when treated with 7 percent hydrated lime. The highest strength developed by treating this soil with any of the quicklimes was less than 1400 psi (9653 kPa). Soil No. 8 is another example of consistently higher strengths when treated with 7 percent hydrated lime. Both of these soils responded better to the quicklimes than the hydrated lime when only 3 percent lime was added.

The grading of the quicklime also had some effect on the reaction with the soil. But again the relative reaction of the 3 quicklimes was not consistent with each of the soils. Some soils developed greater strengths when treated with finely ground quicklime while other soils developed greater strengths with the granular quicklime.

There may be more than one factor contributing to this phenomenon, but the density of the compacted test sample appears to be related. The average test sample dry density for soil No. 9 was 2 to 3 percent greater when 7 percent hydrated lime was used than when 7 percent quicklime was used. When 3 percent lime was used with this same soil, the lower strengths with the hydrated lime were accompanied by lower densities of the test samples. With soils where there was a significant and consistent difference in strength with certain quicklimes, it was also observed that there was a correlation with the compacted densities of the test samples. It is possible that the granularity of the quicklime and the rate at which it hydrates affects the initial flocculation and agglomeration of the soil. This in turn may influence the density and compactability of the test sample.

Another possible contributing factor to the higher strength when hydrated lime was used is the reaction rate of the various soils with the different limes. Studies by others(4) have shown that increased quantities of lime may require longer curing periods to achieve ultimate strength. This is due, at least partially, to the fact that cementing does not occur until the pH of the lime-soil mixture begins to drop. An increased free lime content, whether the result of a higher percentage of hydrated lime or the increased concentration of available calcium oxide in quicklime, will result in a longer delay before the pH of the mixture begins to drop.

It is concluded from these data that each lime-soil combination must be evaluated individually. The reaction and resulting strength of a lime treated soil cannot be reliably estimated from the strengths which develop when the same soil is treated with a different lime product. Soils which respond favorably to lime treatment, however, will normally achieve higher ultimate strengths as the lime content is increased so long as additional pozzolans are available in the soil.

Effect of Curing Procedure on Strength

The rate at which the cementing reaction occurs and the length of time required to achieve a given strength varied with each combination of soil and lime. For some materials, such as Soil No. 3 when treated with 3 percent lime, the reaction is apparently completed within a very short period of time. The measured strength is essentially the same regardless of the method or length of curing. Several other soils, when treated with an equal amount of lime, continued to gain strength at a relatively rapid rate over a long period of time. Some materials gained strength rapidly during the first six months of curing with only minor increases in strength thereafter, but Soil No. 1 gained more strength during the second six months of curing than during the first six months.

The relative rate of reaction also varies considerably with different concentrations of lime in the same soil. Soil No. 3, for example, continued to gain significant strength over an extended period of time when treated with 7 percent lime. The length of the curing period, however, had very little effect on this soil when treated with 3% lime. Soil No. 4, on the other hand, failed to respond to the extended curing periods regardless of the amount of lime added (perhaps for reasons previously discussed).

Curves are plotted in Figure 15 to show the unconfined compressive strengths of the test specimens treated with hydrated lime as the curing time at 72°F (22°C) was increased from 28 to 360 days. The strengths achieved by curing replicate samples for 7 days at 110°F (43°C) are also plotted for comparison. It is obvious from these data that there is no consistant correlation between the strengths of the samples cured by the accelerated procedure and those cured for long periods of time at room temperature. This is apparantly due to the differences in rate of strength gain and differences in the time required to achieve a substantial portion of the "ultimate strength for each combination of lime content and soil. The accelerated curing procedure does, however, provide a fair indication of the strengths that can be expected after approximately two to three months of curing at 72°F (22°C). This strength is probably adequate for design purposes since any changes from this initial strength should be an increase. Also, most construction would probably be done during the summer months so that the material placed on the roadway would gain strength more rapidly than the samples cured at 72°F (22°C). Thus, in summer months the 7 day accelerated cure strength would tend to be conservative.

No apparent advantage was realized by the short term sand bath curing procedure for evaluating the lime/soil reaction. It had been anticipated that exposure of the test samples to free water in the sand bath would cause poorly cemented materials to soften and lose strength. This study showed, however, that samples which had been cured for 5 days at 110°F (43°C) and then subjected to 2 additional days in the sand bath generally had unconfined compressive strengths equal to between 60 and 90 percent of the strengths developed after 7 days at 110°F (43°C). Assuming that the strength gained during this early period of curing is somewhat proportional to the length of the curing period, then the strength at 5 days could not be expected to be more than approximately 70 percent of the strength at 7 days (all at 110°F (43°C)). During the time in the sand bath, the gain in strength would be much slower because of the lower temperature (72°F). It is concluded, then, that the lower strengths of the samples exposed to the sand bath for two days was due in part to the reduced length of time that the material was subjected to the 110°F (43°C) temperature. As a result of this and the effects of other variables, the actual loss of strength due to softening of the cemented material could not be evaluated by the two day sand bath exposure. However, when the sand bath exposure was extended to six months, following an initial cure of 7 days at 110°F (43°C), some effect could be measured . As can be seen in Figure 16, only two of the treated materials gained appreciable strength during the six months in the sand bath when 3 percent hydrated lime was used. The remainder either lost strength or the difference in strength was too small to be significant.

When the soils were treated with 7 percent hydrated lime, eight achieved significantly higher strengths during the sand bath exposure while the other four either maintained their initial strength or lost strength. Three of these four had very low strengths even before exposure in the sand bath. The fourth, Soil No. 12, apparantly gained the major portion of its ultimate strength during the initial curing period so that there was no additional cementing to occur during the extended curing period. It should be noted that when quicklime was added to Soil No. 12, the strength was not as great after the initial cure but there was a significant increase in strength during the sand bath exposure. Over all, it appears that lime-treated soils which develop unconfined compressive strengths in excess of 400 psi (2758 kPa) when cured for 7 days at 110°F (43°C) generally will not soften and lose strength when exposed to free water.

Application of Lime Treatment to Structural Section Design

The current California highway structural section design procedure applies a gravel equivalent factor of 1.2 to all lime treated materials. The large differences in unconfined compressive strength developed by the various soils treated with lime in this study strongly suggests, however, that the same gravel factor should not be automatically assigned to all lime treated materials.

Data developed in this study indicate a distinct division between those soils which ultimately develop into durable, high strength materials and those which do not. The unconfined compressive strength after 7 days at 110°F (43°C) is apparently a reasonably good indicator of these qualities.

Because of the broad range in unconfined compressive strengths that can be expected when different soils are lime treated, it is recommended that the strength of the treated soil be taken into account when designing the roadway structural section. It is suggested that this be done by applying a gravel equivalency factor of $(.9 + \frac{\text{unconfined compressive strength in psi}}{1000})$ to treated soils which achieve an unconfined compressive strength of at least 400 psi (2758 kPa) when cured for 7 days at 110°F (43°C). This provides a value which progressively increases as the strength increases but which is generally less than the 1.7 value assigned to cement treated aggregates using the California Department of Transportation procedure.

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TABLE NO 6

Unconfined Compressive Strengths
Lime Soil Number 1

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	164	158	203	206
	"	-	-	164	199	220	203
	-	28	-	148	183	204	185
	-	180	-	221	268	273	219
	-	360	-	264	465	466	303
	-	"	-	268	455	468	286
	5	-	2	123	124	90	112
	"	-	"	123	137	116	120
	7	-	28	140	155	198	145
	"	-	180	181	185	217	164
5	7	-	-	165	188	205	205
	"	-	-	173	194	239	206
	-	360	-	327	1011	1046	770
	-	"	-	308	972	1046	753
7	7	-	-	171	213	211	215
	"	-	-	176	241	225	217
		28		153	197	213	179
		180		247	489	523	397
		360		647	1221	1291	993
		"		646	1145	1221	1026
	5	-	2	158	127	140	154
	"	-	"	148	170	170	149
	7	-	28	161	226	239	169
	7	-	180	276	423	463	314

*SI equivalent
1 pound-force per square inch (psi) = 6.8948 kilopascals (kPa)

TABLE NO 7

Unconfined Compressive Strengths
Lime Soil Number 2

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	439	549	592	581
	"	-	-	444	618	575	624
	-	28	-	334	278	296	286
	-	180	-	443	630	583	693
	-	360	-	519	823	840	804
	-	"	-	525	815	873	561
	5	-	2	336	501	455	450
	"	-	"	321	480	484	425
	7	-	28	329	557	562	512
	"	-	180	344	610	549	544
5	7	-	-	680	767	770	708
	"	-	-	694	770	712	744
	-	360	-	1178	1374	1290	1232
	-	"	-	1100	1376	1299	1236
7	7	-	-	734	705	641	620
	"	-	-	726	702	636	630
		28		339	320	309	308
		180		1157	1250	1119	1154
		360		1475	1608	1448	1445
		"		1501	1470	1476	1433
	5	-	2	514	482	450	439
	"	-	"	503	453	461	455
	7	-	28	731	689	652	597
	7	-	180	942	1102	1083	1097

TABLE NO 8

Unconfined Compressive Strengths
Lime Soil Number 3

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	308	554	499	434
	"	-	-	335	548	499	491
	-	28	-	297	502	457	460
	-	180	-	351	593	513	559
	-	360	-	363	642	626	623
	-	"	-	370	651	606	595
	5	-	2	296	484	458	456
	"	-	"	271	424	419	455
	7	-	28	299	521	483	471
	"	-	180	282	529	514	497
5	7	-	-	721	910	792	779
	"	-	-	713	895	796	790
	-	360	-	831	1242	1291	1157
	-	"	-	823	1187	1233	1199
7	7	-	-	1001	1028	933	742
	"	-	-	1047	1026	900	759
		28		598	631	529	495
		180		1130	1381	1243	1142
		360		1291	1619	1684	1442
		"		1264	1610	1644	1434
	5	-	2	940	805	722	650
	"	-	"	944	870	689	637
	7	-	28	958	1147	956	820
	7	-	180	1199	1427	1284	1241

TABLE NO 9

Unconfined Compressive Strengths
Lime Soil Number 4

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	119	125	102	106
	"	-	-	121	121	103	108
	-	28	-	105	104	91	93
	-	180	-	125	138	125	123
	-	360	-	131	155	137	126
	-	"	-	130	154	135	133
	5	-	2	59	93	99	91
	"	-	"	76	94	99	89
	7	-	28	76	91	94	90
	"	-	180	63	87	84	79
5	7	-	-	129	133	129	136
	"	-	-	135	137	125	134
	-	360	-	154	200	196	189
	-	"	-	149	191	182	191
7	7	-	-	152	153	147	140
	"	-	-	153	153	148	155
		28		124	128	131	144
		180		171	181	192	179
		360		187	256	236	231
		"		206	264	236	230
	5	-	2	122	124	133	153
	"	-	"	117	124	134	140
	7	-	28	109	129	128	137
	7	-	180	110	141	143	142

TABLE NO 10

Unconfined Compressive Strengths
Lime Soil Number 5

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	397	549	584	470
	"	-	-	390	547	598	433
	-	28	-	302	313	382	249
	-	180	-	478	731	754	628
	-	360	-	656	1088	1063	980
	-	"	-	670	1070	1040	874
	5	-	2	308	465	440	396
	"	-	"	318	437	461	360
	7	-	28	349	481	509	397
	"	-	180	330	568	578	478
5	7	-	-	631	603	650	545
	"	-	-	621	575	654	550
	-	360	-	1339	1378	1479	1525
	-	"	-	1413	1371	1513	1479
7	7	-	-	625	532	587	540
	"	-	-	631	567	615	567
		28		327	316	322	307
		180		1101	1029	1026	1057
		360		1776	1382	1688	1813
		"		1766	1367	1649	1835
	5	-	2	425	436	383	380
	"	-	"	404	432	381	381
	7	-	28	658	592	582	588
	7	-	180	1042	1033	918	995

TABLE NO 11

Unconfined Compressive Strengths
Lime Soil Number 6

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type: Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	82	103	102	97
	"	-	-	86	96	114	105
	-	28	-	84	91	100	107
	-	180	-	69	90	106	106
	-	360	-	118	135	165	159
	-	"	-	93	138	144	125
	5	-	2	46	76	79	80
	"	-	"	49	78	75	76
	7	-	28	46	77	63	65
	"	-	180	40	57	60	57
5	7	-	-	144	217	236	254
	"	-	-	148	225	253	238
	-	360	-	177	334	377	410
	-	"	-	187	332	363	399
7	7	-	-	226	365	366	473
	"	-	-	238	393	372	506
		28		249	373	445	540
		180		228	424	507	617
		360		292	486	633	721
		"		304	559	673	805
	5	-	2	193	295	360	413
	"	-	"	198	295	362	432
	7	-	28	174	300	347	443
	7	-	180	124	268	343	388

TABLE NO 12

Unconfined Compressive Strengths
Lime Soil Number 7

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	159	211	207	201
	"	-	-	164	201	209	186
	-	28	-	123	158	184	190
	-	180	-	165	296	325	293
	-	360	-	305	523	569	508
	-	"	-	301	538	559	493
	5	-	2	115	123	147	116
	"	-	"	111	123	142	110
	7	-	28	118	154	174	146
	"	-	180	133	189	202	175
5	7	-	-	187	196	207	193
	"	-	-	183	202	198	192
	-	360	-	420	494	561	453
	-	"	-	427	549	568	494
7	7	-	-	191	198	201	187
	"	-	-	192	208	192	201
		28		142	152	168	159
		180		252	290	297	279
		360		465	524	557	496
		"		467	562	557	508
	5	-	2	144	133	144	118
	"	-	"	145	140	142	128
	7	-	28	157	168	172	159
	7	-	180	206	229	213	212

TABLE NO 13

Unconfined Compressive Strengths
Lime Soil Number 8

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	545	636	646	553
	"	-	-	551	661	646	598
	-	28	-	521	594	598	529
	-	180	-	699	1009	1021	882
	-	360	-	778	1019	1091	970
	-	"	-	764	1002	1067	927
	5	-	2	427	445	373	337
	"	-	"	410	435	351	363
	7	-	28	382	463	247	244
	"	-	180	482	550	340	384
5	7	-	-	757	684	733	634
	"	-	-	704	674	730	627
	-	360	-	1296	1329	1353	1212
	-	"	-	1298	1325	1314	1271
7	7	-	-	678	619	641	589
	"	-	-	733	628	675	575
		28		572	505	532	493
		180		1284	962	1055	921
		360		1572	1240	1300	1138
		"		1602	1252	1273	1093
	5	-	2	495	466	468	463
	"	-	"	521	479	458	458
	7	-	28	677	617	652	596
	7	-	180	1084	947	951	907

TABLE NO 14

Unconfined Compressive Strengths
Lime Soil Number 9

% Lime	Curing Time (days) 110°	72°	Sand Bath	Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	770	709	840	680
	"	-	-	790	702	800	604
	-	28	-	434	482	512	443
	-	180	-	898	1128	1183	877
	-	360	-	1123	1459	1628	1409
	-	"	-	1087	1453	1578	1478
	5	-	2	659	642	653	583
	"	-	"	649	596	609	639
	7	-	28	799	800	875	910
	"	-	180	752	969	874	886
5	7	-	-	747	687	731	700
	"	-	-	887	668	724	702
	-	360	-	1753	1569	1638	1518
	-	"	-	1810	1499	1501	1497
7	7	-	-	699	613	604	630
	"	-	-	751	581	626	638
		28		381	357	362	345
		180		1287	991	882	850
		360		2006	1422	1304	1371
		"		1981	1292	1335	1383
	5	-	2	604	413	307	407
	"	-	"	587	441	378	394
	7	-	28	939	588	569	977
	7	-	180	1220	958	950	977

Unconfined Compressive Strength (psi*), Lime Type: Hydrate, Fine Quick, Coarse Quick, 3/8 Quick

TABLE NO 15

Unconfined Compressive Strengths
Lime Soil Number 10

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	533	461	407	507
	"	-	-	541	468	485	475
	-	28	-	296	320	276	302
	-	180	-	733	833	669	798
	-	360	-	898	879	737	846
	-	"	-	822	938	843	799
	5	-	2	403	443	356	406
	"	-	"	426	446	380	398
	7	-	28	494	539	521	535
	"	-	180	639	807	778	721
5	7	-	-	539	525	481	491
	"	-	-	541	536	520	417
	-	360	-	1170	1121	878	994
	-	"	-	1333	1219	855	1074
7	7	-	-	533	528	488	468
	"	-	-	544	468	492	462
		28		288	309	296	272
		180		894	847	775	740
		360		1214	1248	1012	1001
		"		1300	1127	1021	1162
	5	-	2	366	413	361	392
	"	-	"	389	413	403	375
	7	-	28	531	597	564	494
	7	-	180	1031	896	954	937

TABLE NO 16

Unconfined Compressive Strengths
Lime Soil Number 11

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type: Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	427	514	444	453
	"	-	-	485	491	527	439
	-	28	-	267	297	316	284
	-	180	-	663	892	881	883
	-	360	-	843	1301	1253	1119
	-	"	-	986	1213	1267	1205
	5	-	2	317	349	326	345
	"	-	"	262	317	372	377
	7	-	28	446	494	449	426
	"	-	180	605	747	663	680
5	7	-	-	470	473	513	476
	"	-	-	474	477	519	468
	-	360	-	1317	1174	1200	1156
	-	"	-	1362	1280	1406	1265
7	7	-	-	411	422	452	456
	"	-	-	435	433	412	458
		28		264	267	246	260
		180		784	875	865	791
		360		1172	1283	1341	1133
		"			1159	1306	1089
	5	-	2	311	248	314	239
	"	-	"	266	255	297	256
	7	-	28	383	423	436	358
	7	-	180	761	764	736	725

TABLE NO 17

Unconfined Compressive Strengths
Lime Soil Number 12

% Lime	Curing Time (days) 110°	72°	Sand Bath	Unconfined Compressive Strength (psi*) Lime Type Hydrate	Fine Quick	Coarse Quick	3/8 Quick
3	7	-	-	433	567	557	502
	"	-	-	433	555	535	511
	-	28	-	364	498	509	484
	-	180	-	443	616	619	649
	-	360	-	544	731	690	754
	-	"	-	553	730	775	736
	5	-	2	375	450	390	418
	"	-	"	334	451	421	439
	7	-	28	431	510	512	461
	"	-	180	373	536	439	524
5	7	-	-	629	618	668	683
	"	-	-	633	672	717	709
	-	360	-	841	856	853	787
	-	"	-	805	846	927	817
7	7	-	-	846	579	592	543
	"	-	-	801	604	575	547
		28		543	419	446	397
		180		858	961	868	886
		360		1058	925	898	895
		"		1058	956	867	927
	5	-	2	589	440	460	422
	"	-	"	569	448	470	466
	7	-	28	843	673	654	548
	7	-	180	810	1044	918	799

FIGURE 2

EFFECTS OF CURING PROCEDURES ON UNCONFINED COMPRESSIVE STRENGTHS LIME-SOIL NUMBER 1

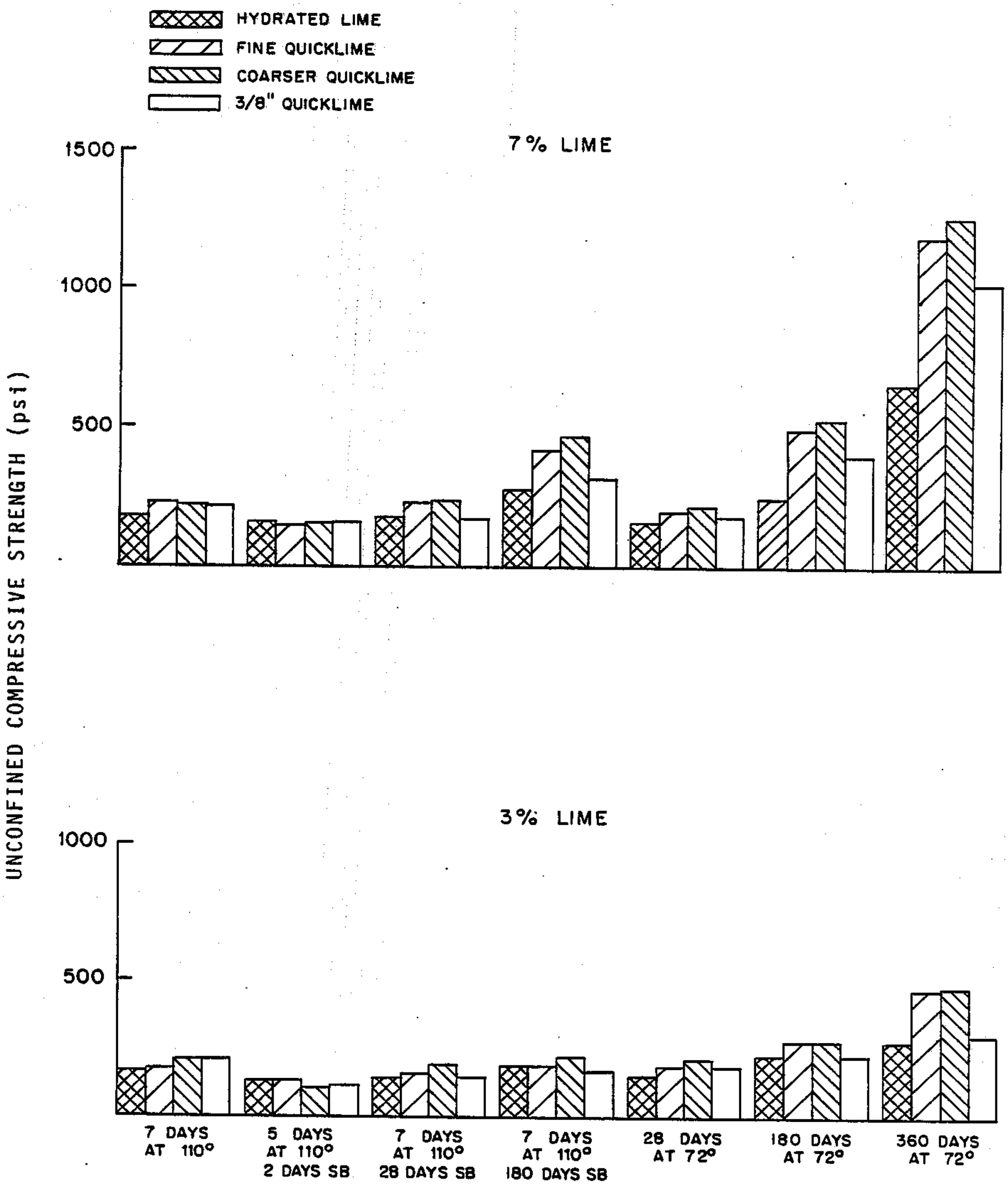


FIGURE 3

EFFECTS OF CURING PROCEDURES ON
UNCONFINED COMPRESSIVE STRENGTHS
LIME-SOIL NUMBER 2

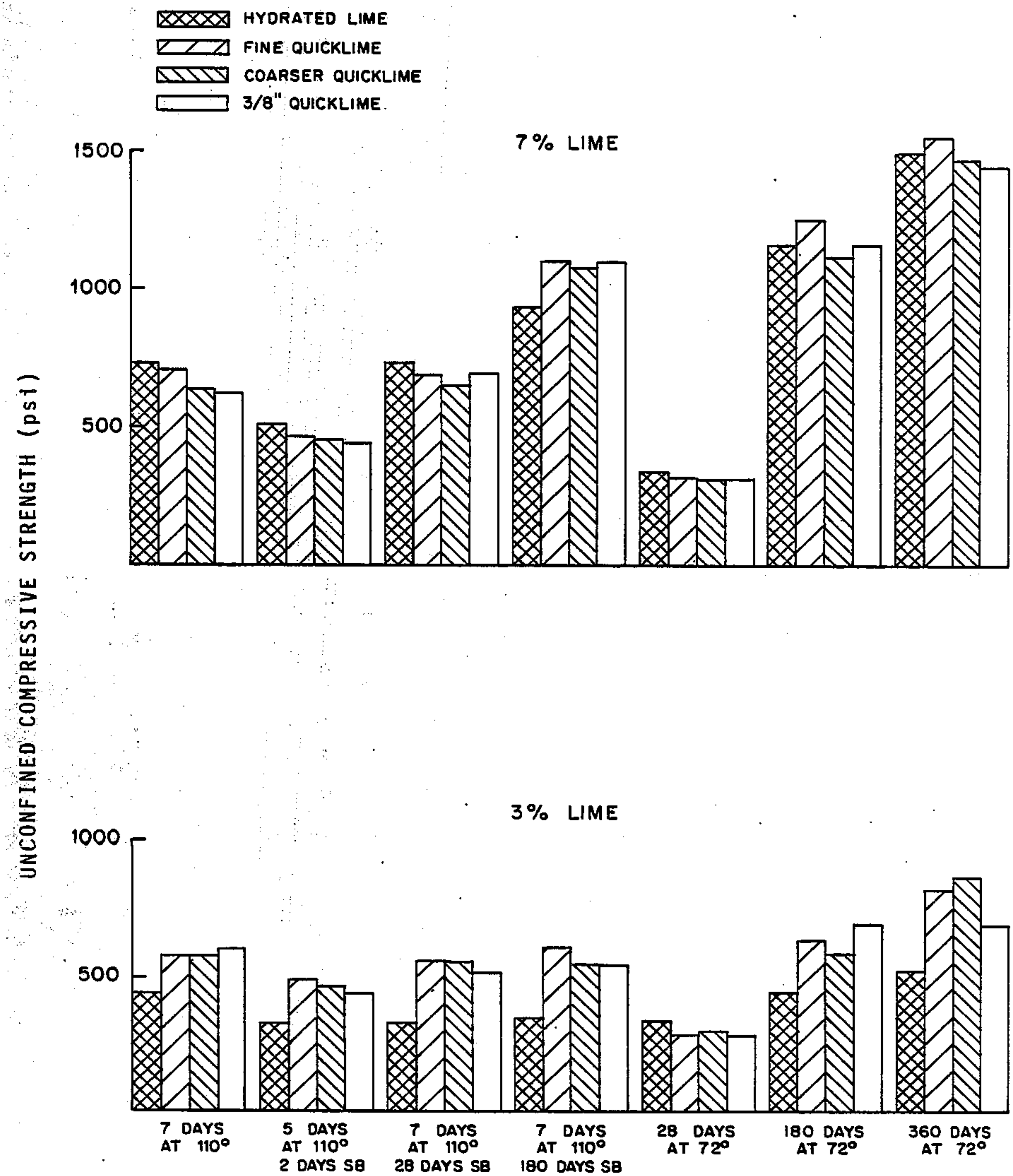


FIGURE 4

EFFECTS OF CURING PROCEDURES ON
UNCONFINED COMPRESSIVE STRENGTHS
LIME-SOIL NUMBER 3

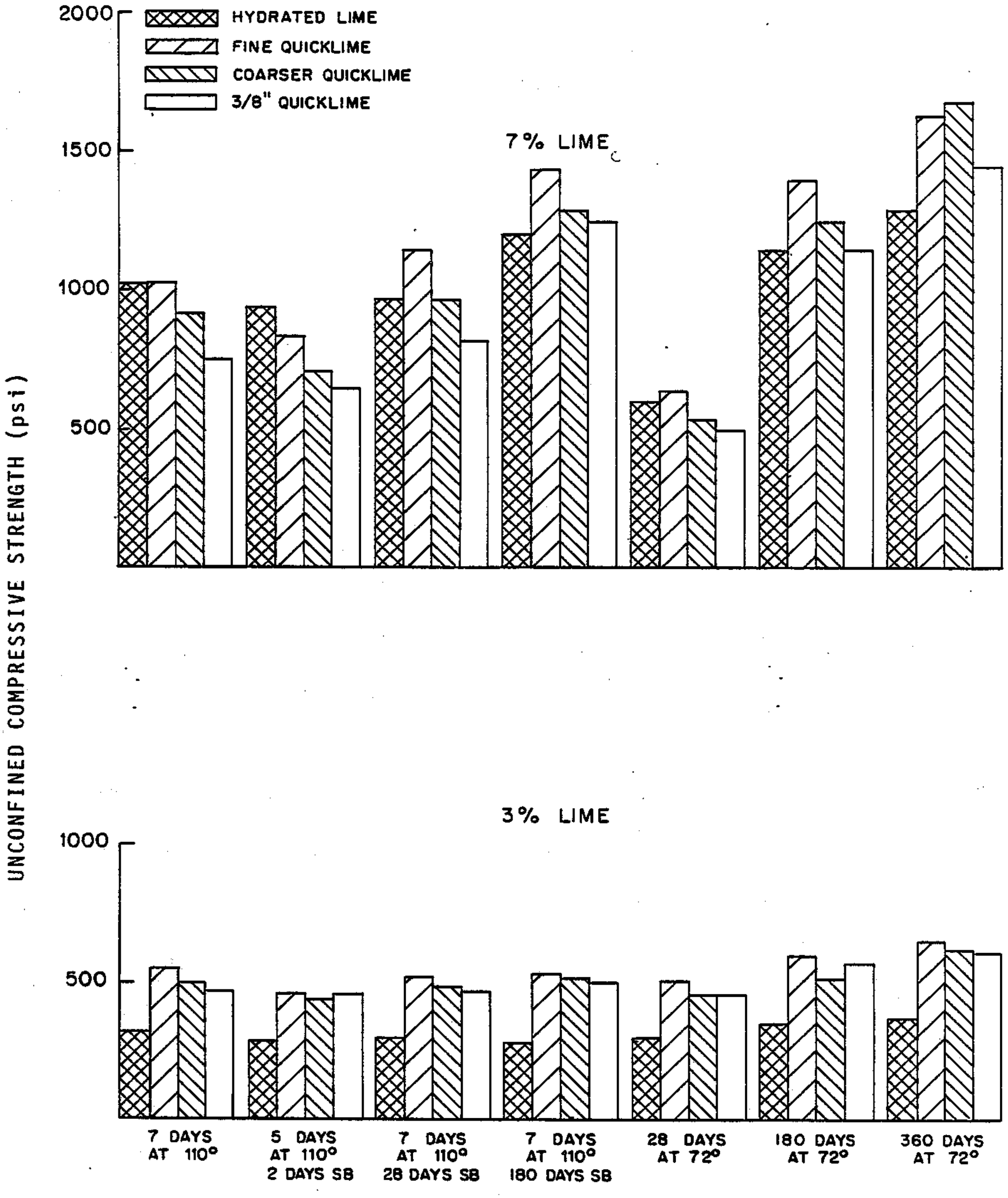


FIGURE 5

EFFECTS OF CURING PROCEDURES ON
UNCONFINED COMPRESSIVE STRENGTHS
LIME-SOIL NUMBER 4

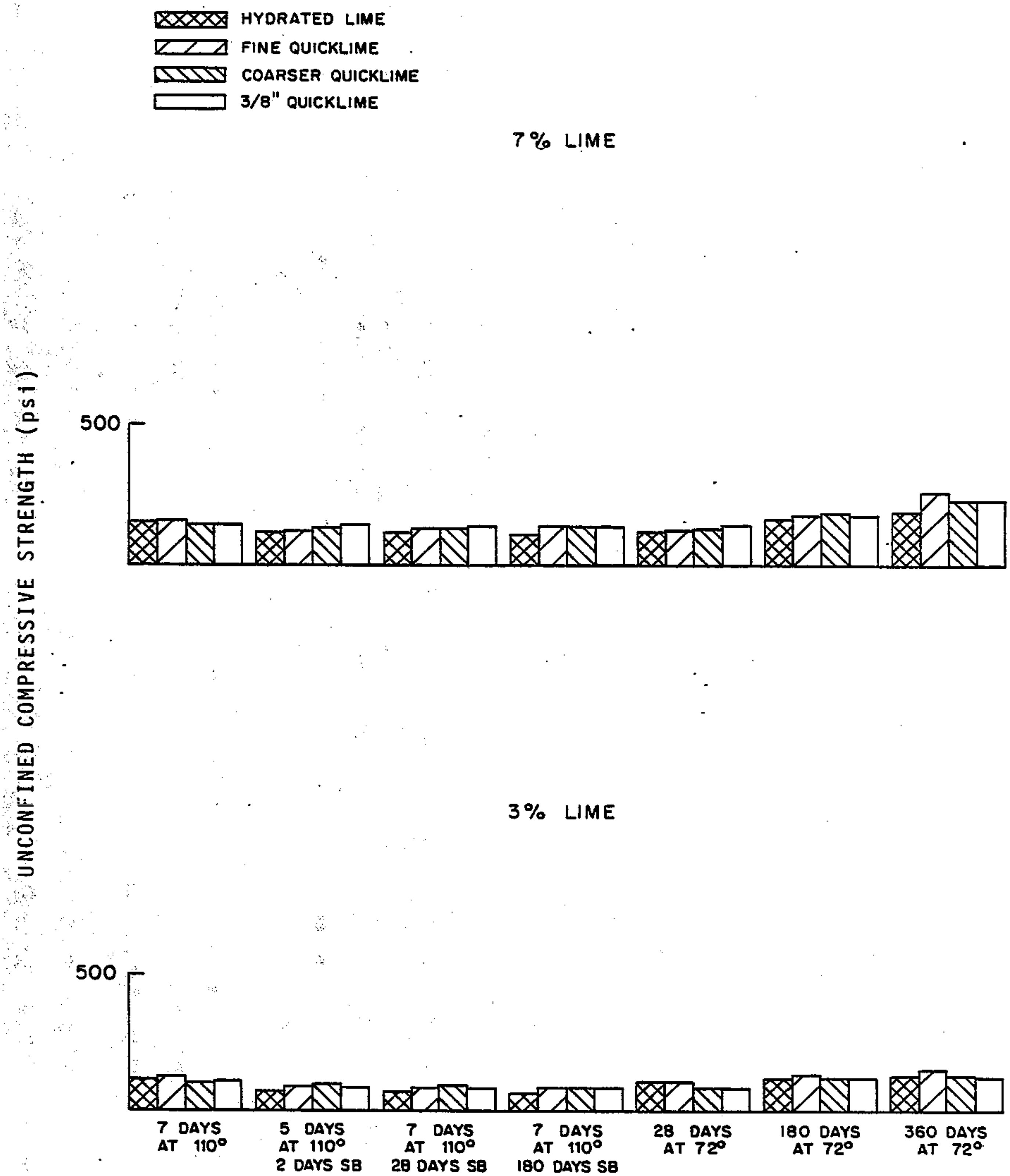


FIGURE 6

EFFECTS OF CURING PROCEDURES ON UNCONFINED COMPRESSIVE STRENGTHS LIME-SOIL NUMBER 5

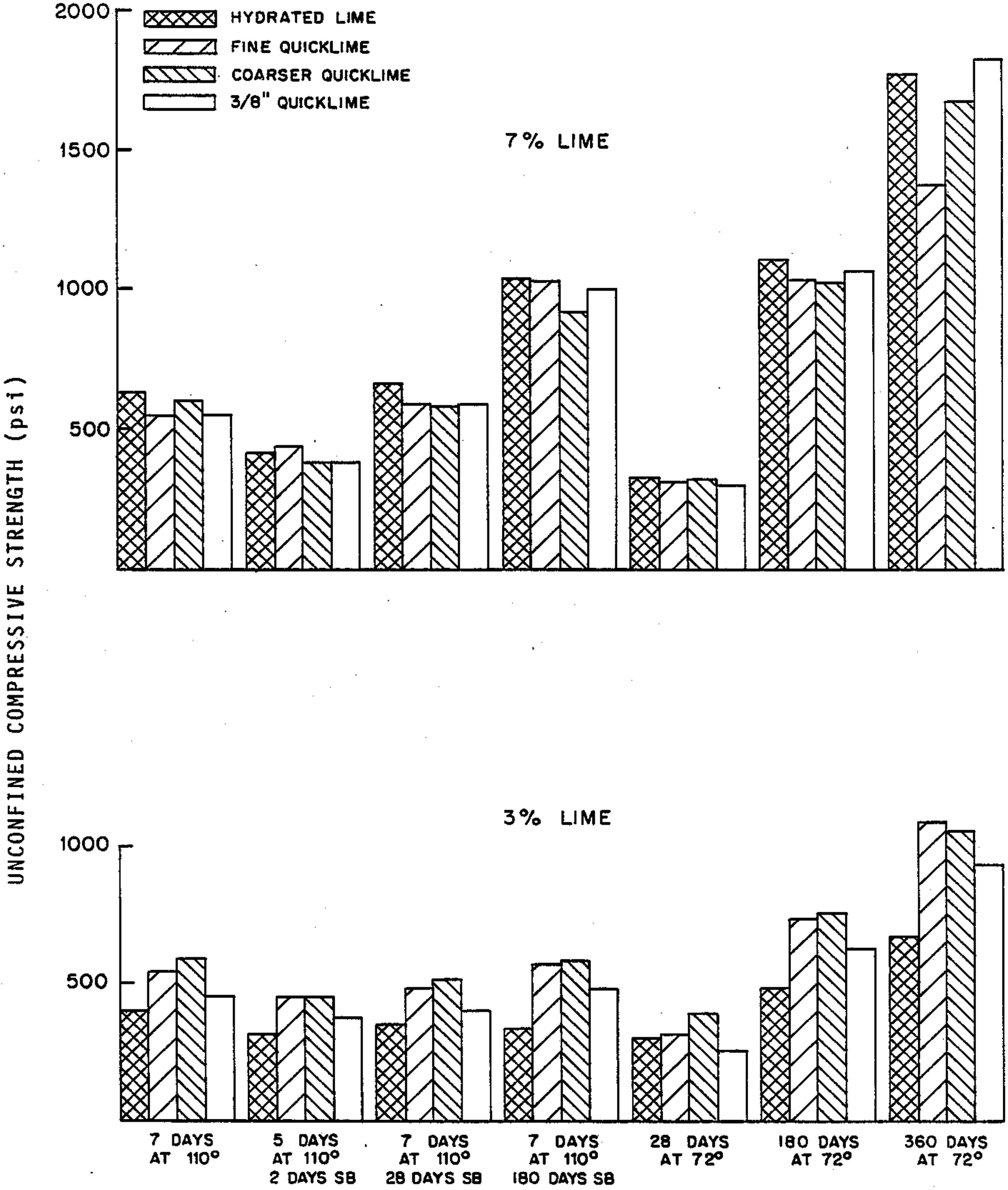


FIGURE 7

EFFECTS OF CURING PROCEDURES ON UNCONFINED COMPRESSIVE STRENGTHS LIME-SOIL NUMBER 6

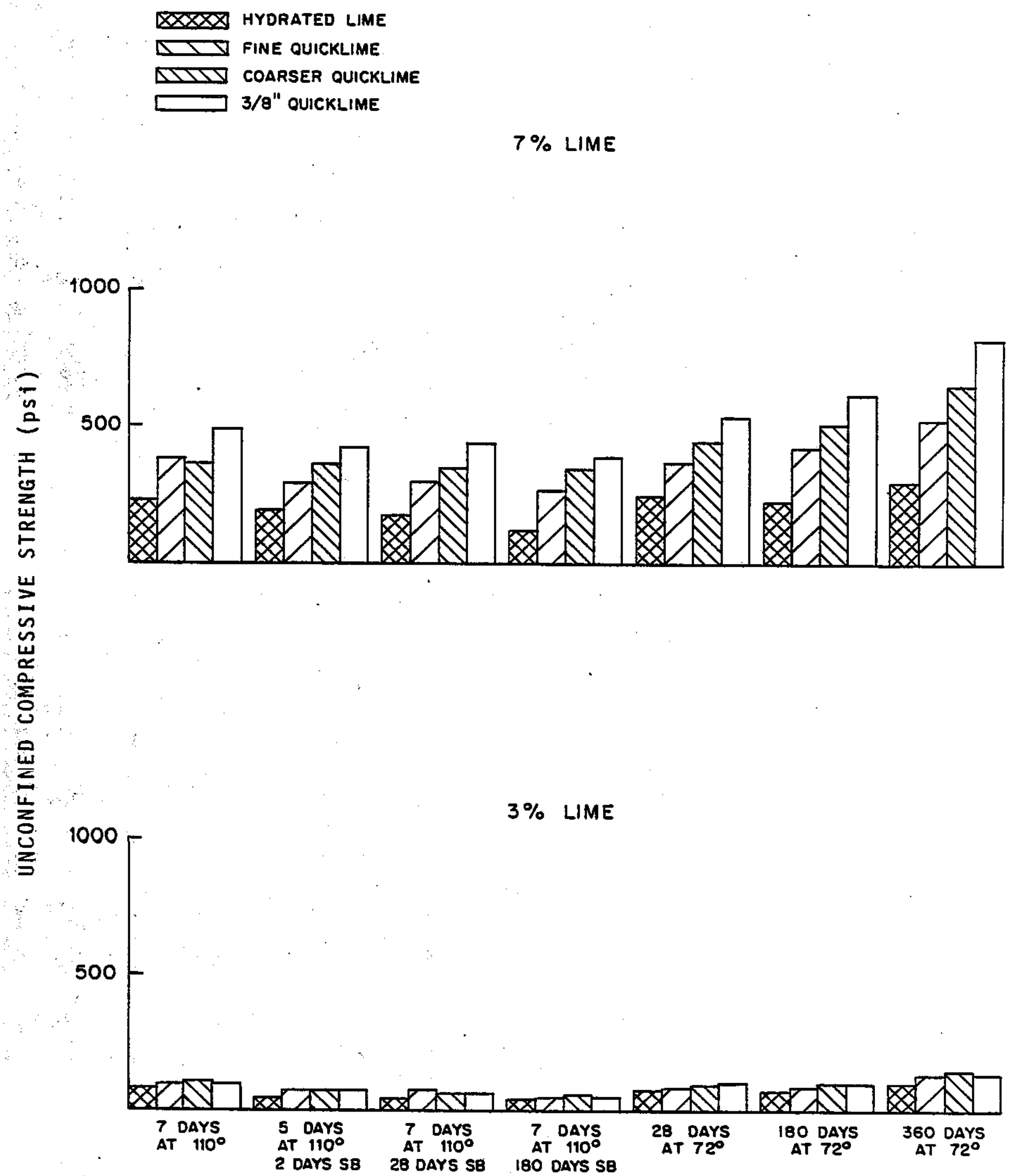


FIGURE 8

EFFECTS OF CURING PROCEDURES ON
UNCONFINED COMPRESSIVE STRENGTHS
LIME-SOIL NUMBER 7

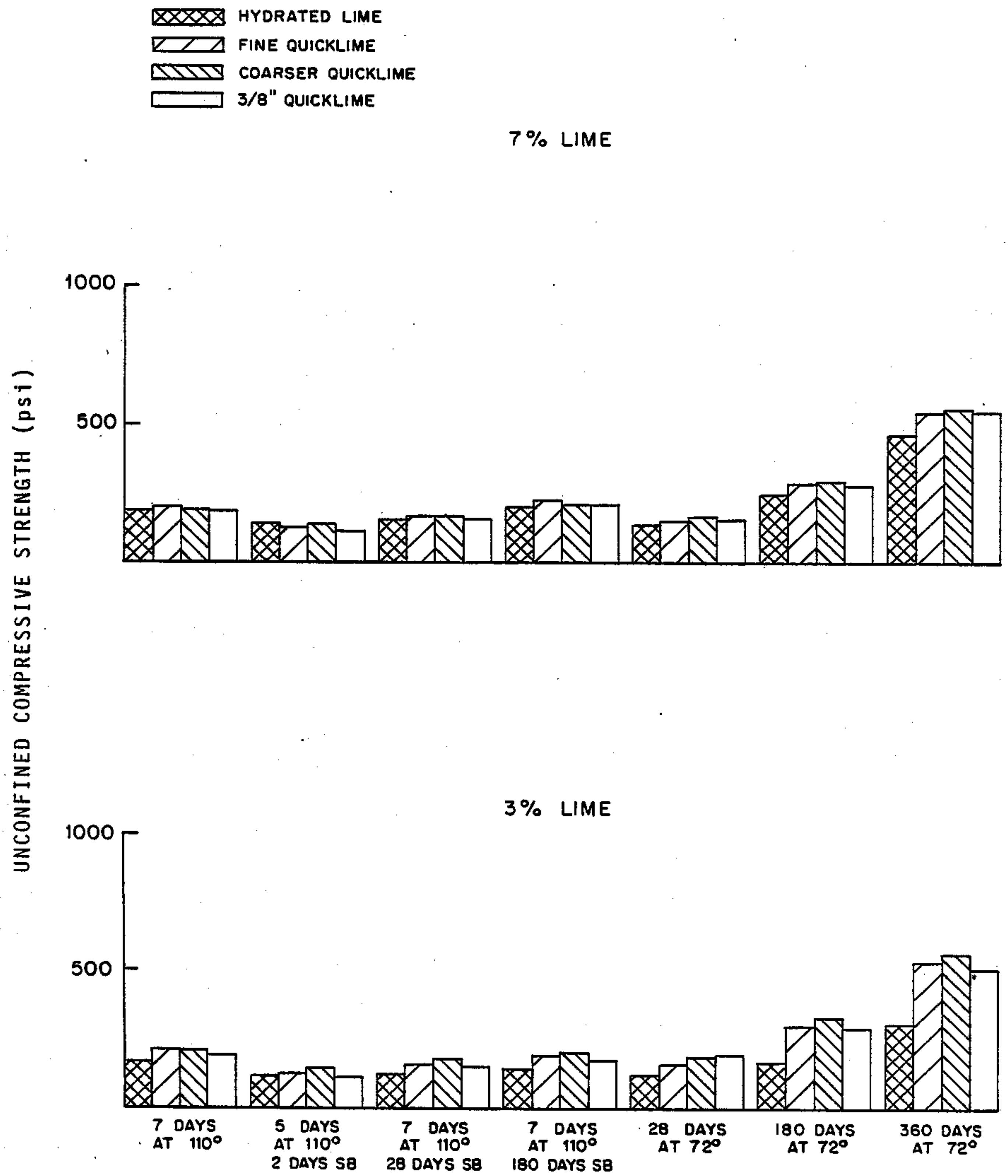


FIGURE 9

EFFECTS OF CURING PROCEDURES ON
UNCONFINED COMPRESSIVE STRENGTHS
LIME-SOIL NUMBER 8

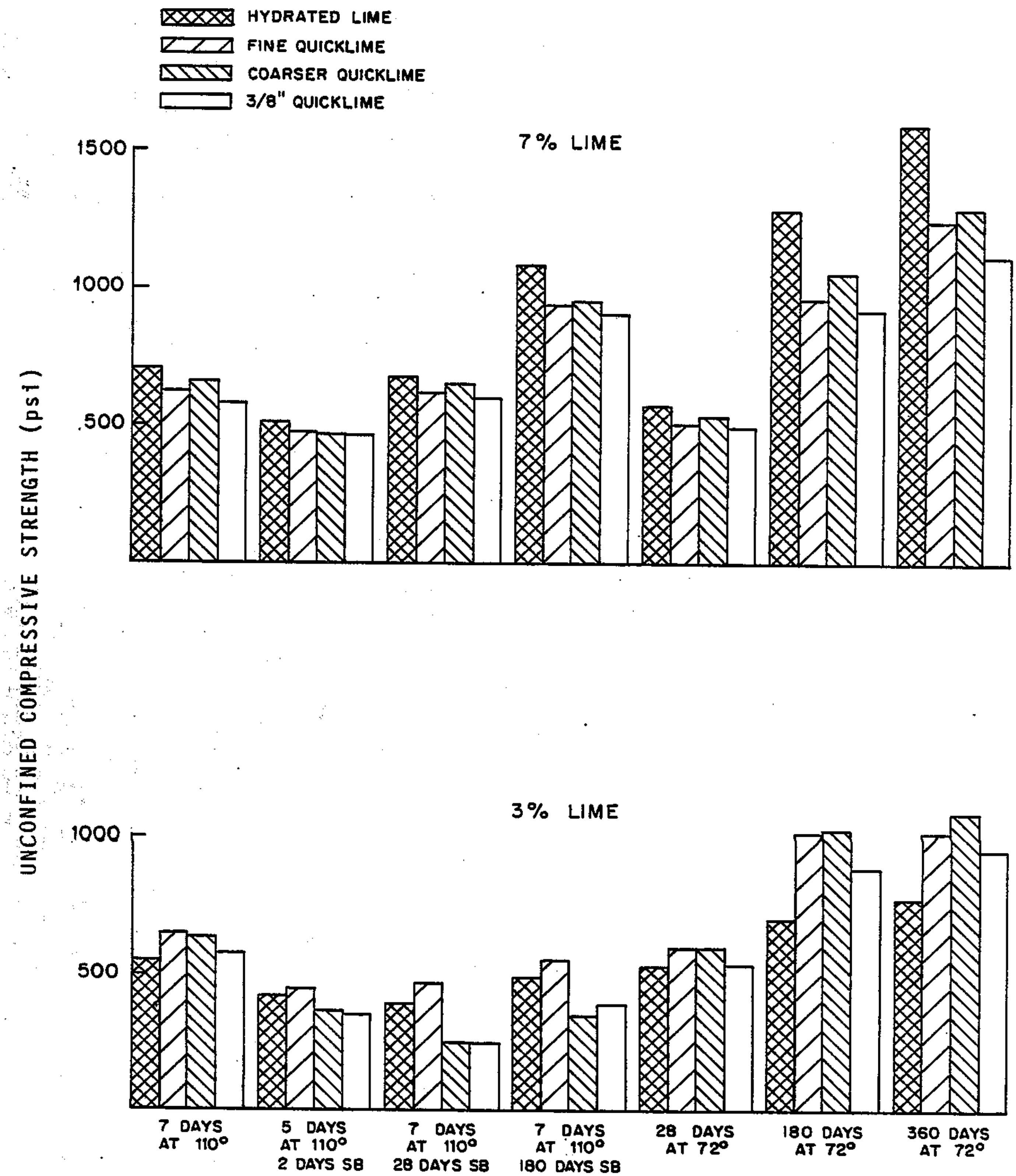


FIGURE 12

EFFECTS OF CURING PROCEDURES ON UNCONFINED COMPRESSIVE STRENGTHS LIME-SOIL NUMBER 11

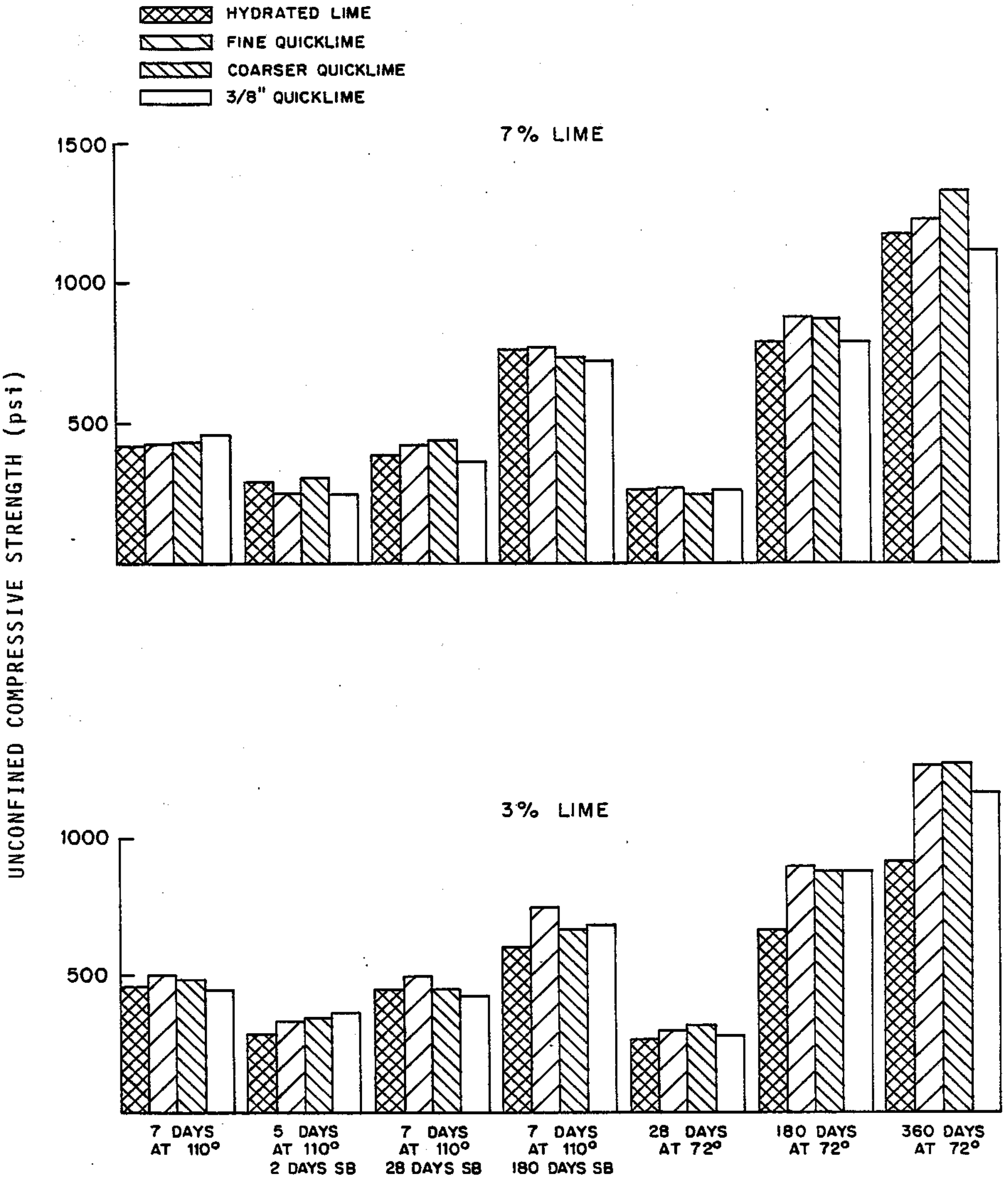


FIGURE 13

EFFECTS OF CURING PROCEDURES ON
UNCONFINED COMPRESSIVE STRENGTHS
LIME-SOIL NUMBER 12

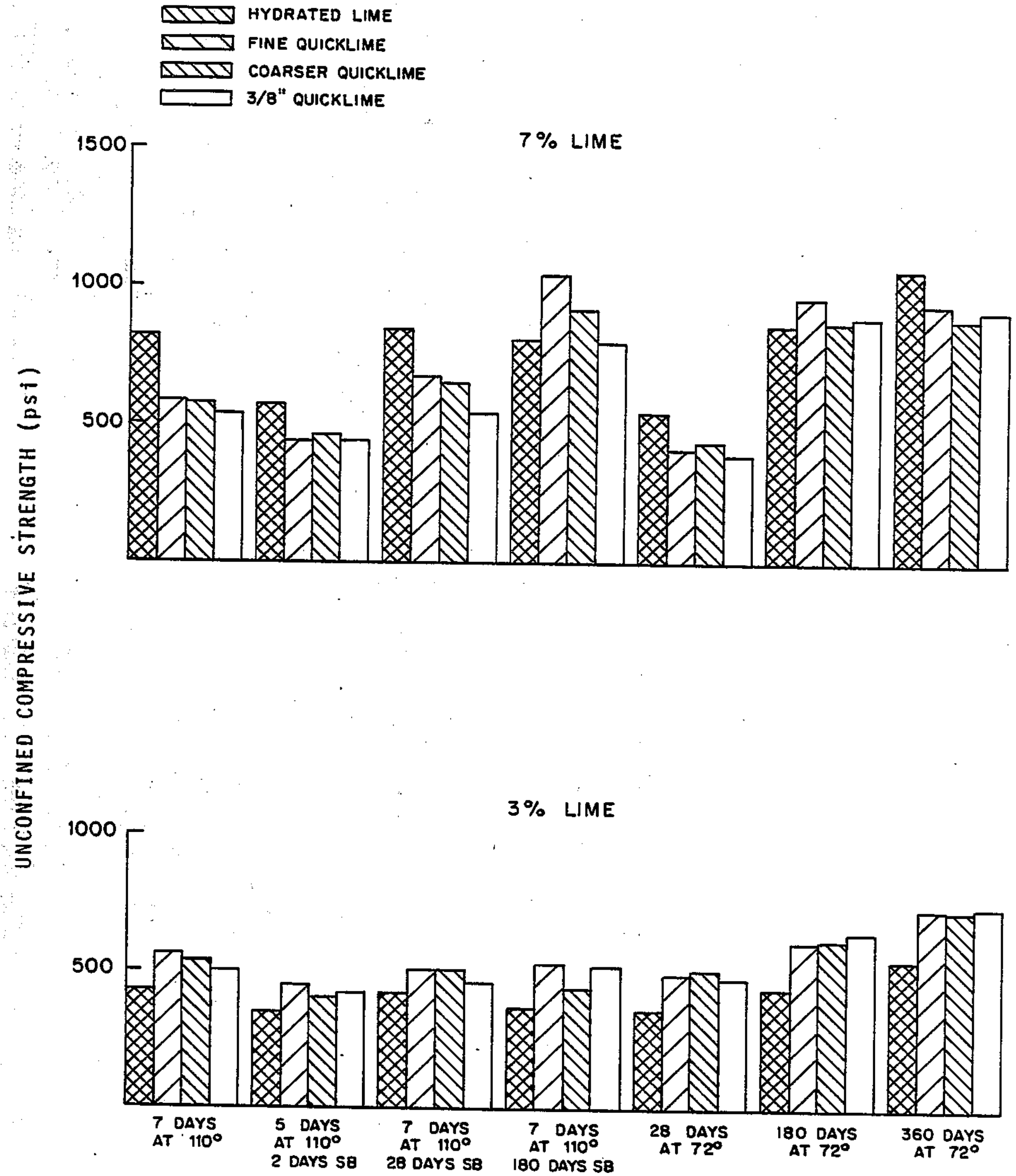


FIGURE 14

EFFECTS OF CURING PROCEDURES ON UNCONFINED COMPRESSIVE STRENGTHS AVERAGE OF ALL TESTED SOILS

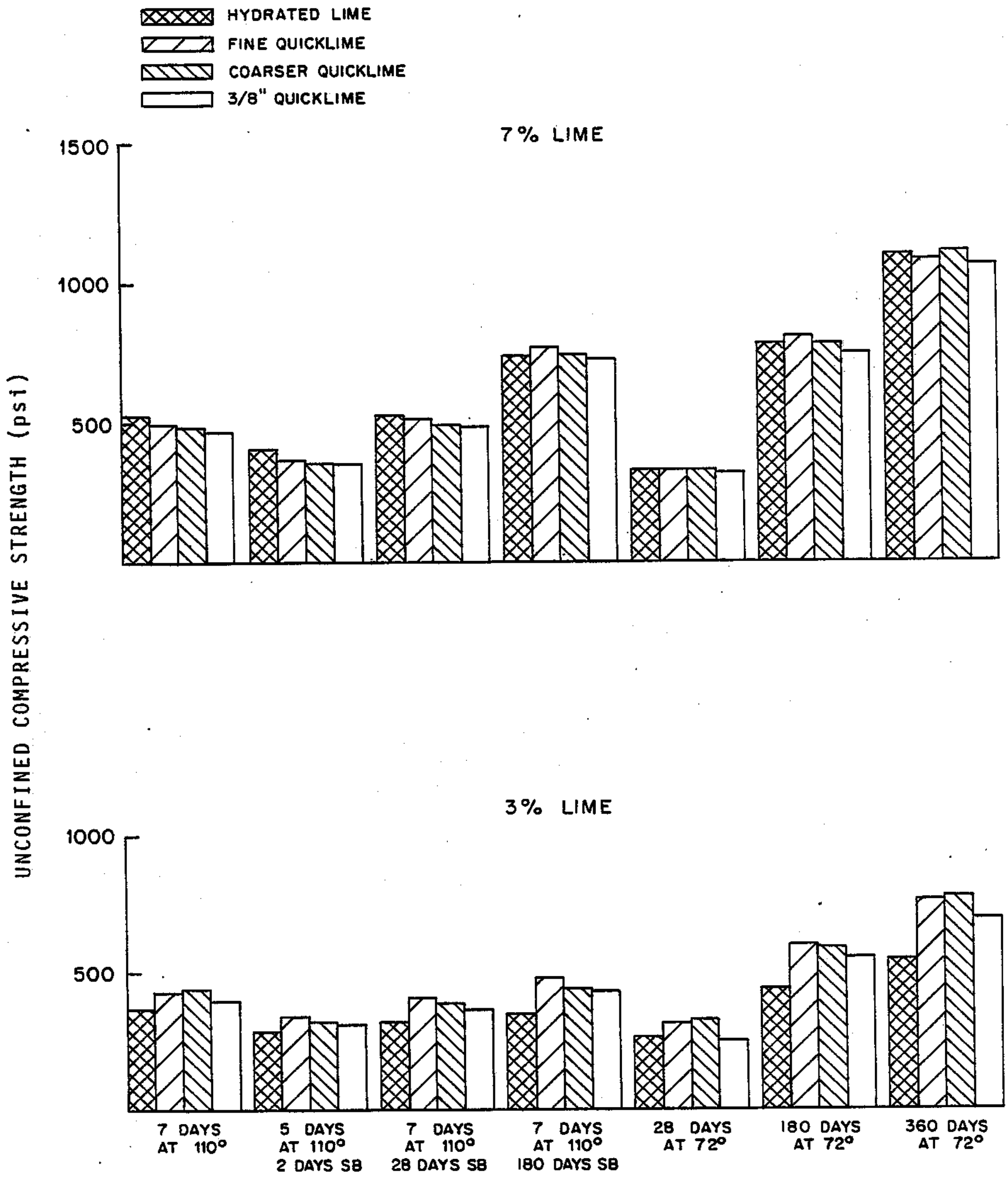


FIGURE 15

COMPARISON OF STRENGTH AFTER 7 DAYS AT 110°F (43°C) WITH STRENGTH INCREASES AT 72°F (22°C)

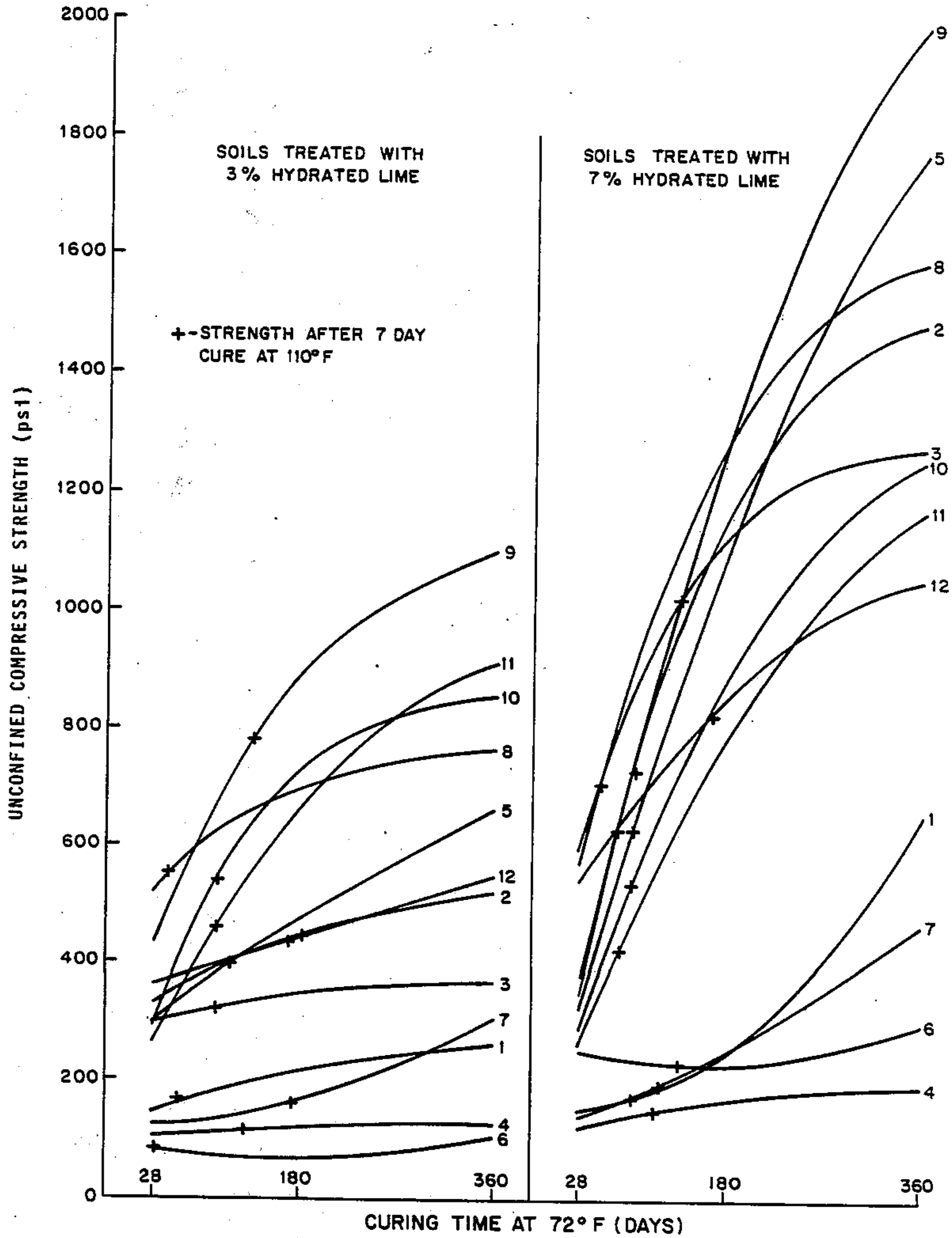
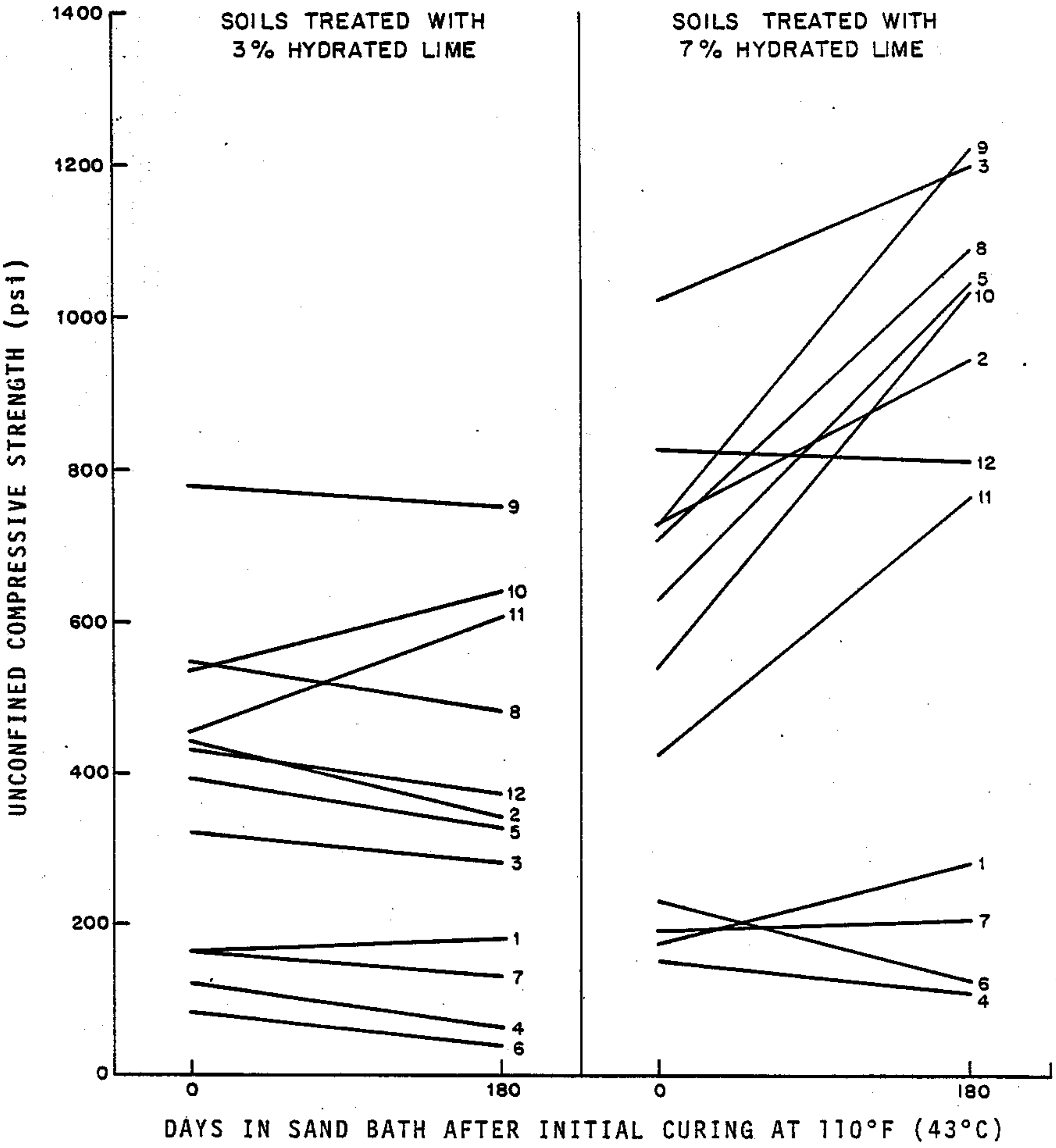


FIGURE 16

EFFECT OF EXPOSURE IN SAND BATH



TENTATIVE METHOD OF TEST FOR UNCONFINED COMPRESSIVE STRENGTH OF LIME TREATED SOILS AND AGGREGATES

SCOPE

This test is used to determine the unconfined compressive strength of lime treated soils. Use is made of portions of Test Methods No. Calif. 216 for optimum moisture, No. Calif. 301 for compaction and No. Calif. 312 for mold, liner and testing.

PROCEDURE

A. Apparatus

1. Riffle splitter, with chutes 3/4 inch wide.
2. Scales, 5000 gram capacity, accurate to 1 gram.
3. Scales, 500 gram capacity, accurate to 0.1 gram.
4. Water spray metering device with turntable.
5. Mixing pans, trowel and 1/2 gallon containers with lids.
6. Kneading compactor.
7. Compactor accessories.
    a. Solid wall compaction mold and accessories shown in Test Method No. Calif. 312, Figure IV.
    b. Compactor mold holder for use with solid wall mold.
    c. 20 inch long feed trough and spatula.
    d. 3-15/16 inch diameter by 1/8 inch rubber discs.
8. Four inch by four inch liners and caps.
9. Masking or adhesive tape.

10. Two six by six inch glass plates for each specimen.

11. Compressive testing machine with spherically seated head.

12. Apparatus for measuring 4 inch high specimens.

13. Oven capable of maintaining 110°F.

14. Six inch diameter by 5 inch high liners and 9 inch diameter by 1-1/2 inch deep pans for sand bath.

15. Hydrocal.

B. Preparation of Soil

1. Refer to Test Method No. Calif. 201 for preparation of the soil sample.

C. Determining Optimum Moisture

The same general procedure described in Test Method No. Calif. 216 shall be used for adjusting the moisture content of individual specimens. Compaction of the test specimens shall be according to Part E. of this procedure.

1. Thoroughly mix the soil, lime and initial water.

   a. Use the same lime content as will be used in the compressive strength specimens.

   b. When tests are to be performed using varying lime contents, determine optimum moisture for at least two lime contents. Moisture requirements for intermediate lime contents may be interpolated. Do not interpolate for a lime content which differs by more than 1 percent from a determined content.

   c. Initial water shall be at least 50% of the optimum amount.

2. Loose cure the mixed material for 16-24 hours in an airtight container.

3. At the end of the loose curing period, adjust the moisture content of the individual test specimens as necessary to result in a range in moisture content which will be above and below the optimum moisture required for maximum density.

D. Preparing Treated Materials

1. Dry mix the soil and desired amount of lime using a hand trowel and a circular pan.

2. Add the total amount of water required for optimum moisture content as determined in Part C. Use the mixing procedure described in Test Method No. Calif. 301.

   a. Do not mix longer than 1 minute.

   b. Do not deliberately break up lime lumps which do not disperse during the normal mixing procedure.

3. Seal the prepared mixture in an airtight container and allow to loose cure for 16 to 24 hours.

4. At the end of the loose curing period lightly remix the material to be sure there are no lumps or lime pockets. If lumps or lime pockets are present continue mixing until the material is uniform in texture and free of lumps.

E. Compacting Test Specimens

Compact the prepared material into 4" x 4" diameter tin liners using the mechanical compaction mold and the kneading compactor.

1. Cover the bottom of the mold to a depth of approximately 3/4 inch with the prepared material.

2. Start the compactor and feed the remainder of the prepared material into the mold in 20 equal parts. With the compactor applying a foot pressure of 250 psi, add one part of material with each tamp of the compactor. Apply 10 additional tamps to level and set the material.

3. Apply 100 tamps to the specimen at a compactor foot pressure of 350 psi.

4. Place the mold and sample in the testing press and apply a 4400 lb. (350 psi) load at the rate of 2,000 pounds per minute.

5. Remove the specimen in its tin liner from the compaction mold.

6. Measure the height and weight of the specimen.

7. Place lids on both ends of the specimen and seal with tape.

F. Curing the Test Specimen

1. Method 1 - Place the sealed specimens in a 110°F ± 5°F oven for seven days.

2. Method 2 - Place the sealed specimens in a 110°F ± 5°F oven for five days. At the end of the 5 days remove the test specimen from the tin liner and place in a saturated sand bath for two days.

G. Testing for Compressive Strength

1. Remove the tin liners from the oven samples and clean the loose sand from the surfaces of the sand bath specimens.

2. Cap both ends with plaster of paris using glass plates to form a smooth surface.

3. Apply a load to the test specimen using a testing press set to travel at a rate of 0.05 inch per minute.

4. Record the total load required to fracture the specimen.

5. Report the compressive strength of the specimen as psi.

H. Reporting of Results

1. Report compressive strength as pounds per square inch, which equals the total compressive load divided by the end area of the test specimen.

   For the standard four inch diameter test specimen, the end area is 12.57 square inches.

   An optional method for calculating compressive strength is to multiply the total compression load by 0.080.